SPE DISTINGUISHED LECTURER

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SPE DISTINGUISHED LECTURER

Drill Rig Control Systems: Detecting Dysfunction and Improving Behavior

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Retired: ExxonMobil

Society of Petroleum Engineers

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Distinguished Lecturer Program
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Original presentation in the 2022/2023 DL Program

Outline

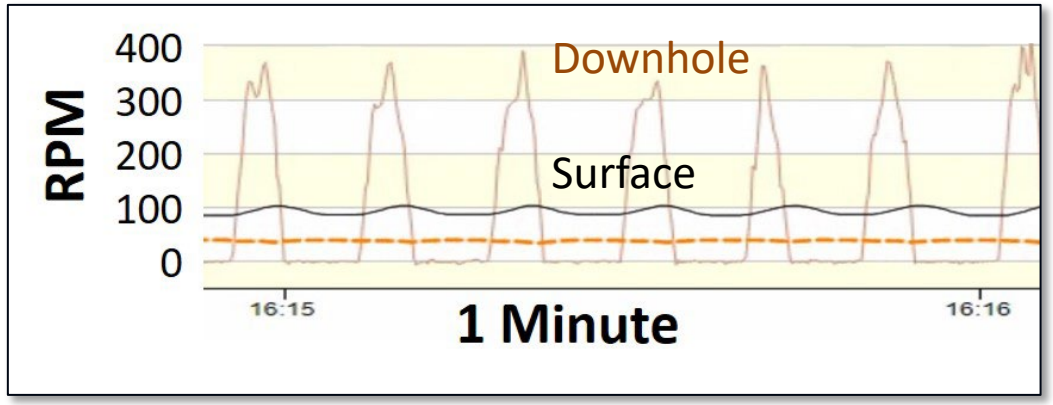
- Physics of Stick Slip
- Why should we care about rig control systems?
  - Auto Driller Theory & Auto Driller Practice
  - Drilling System Response - Tuning & Re-tuning the System
- Detecting Dysfunction
  - Model of Drilling Process with a Proportional-Integral Controller
  - Improving Behavior
  - Auto Tuning
  - Multiple Loops In Control - WOB, ROP, Torque, Diff Pressure
- Managing Torque Limits
- Conclusions and Take Aways

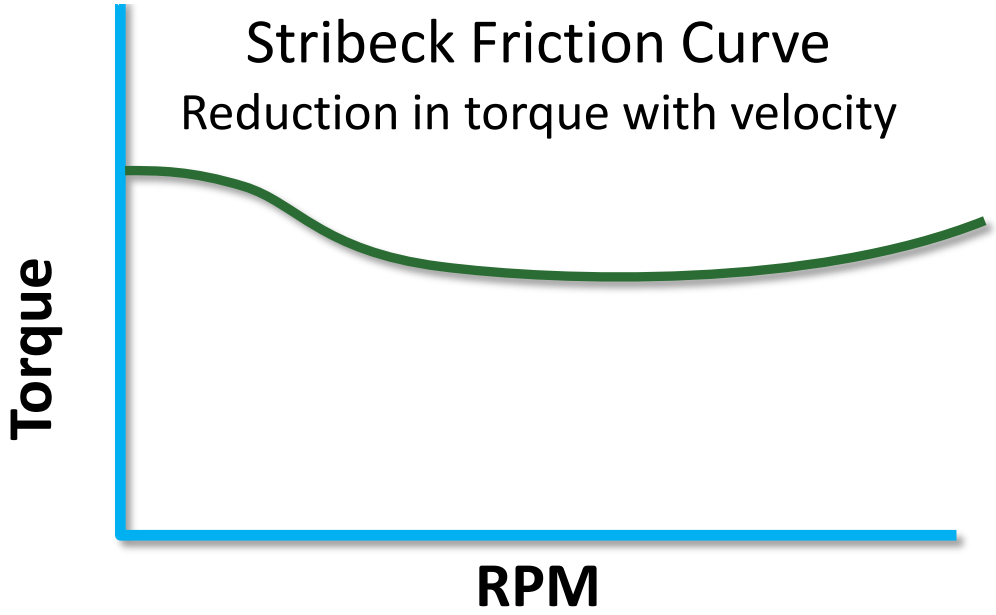
Physics of Stick Slip

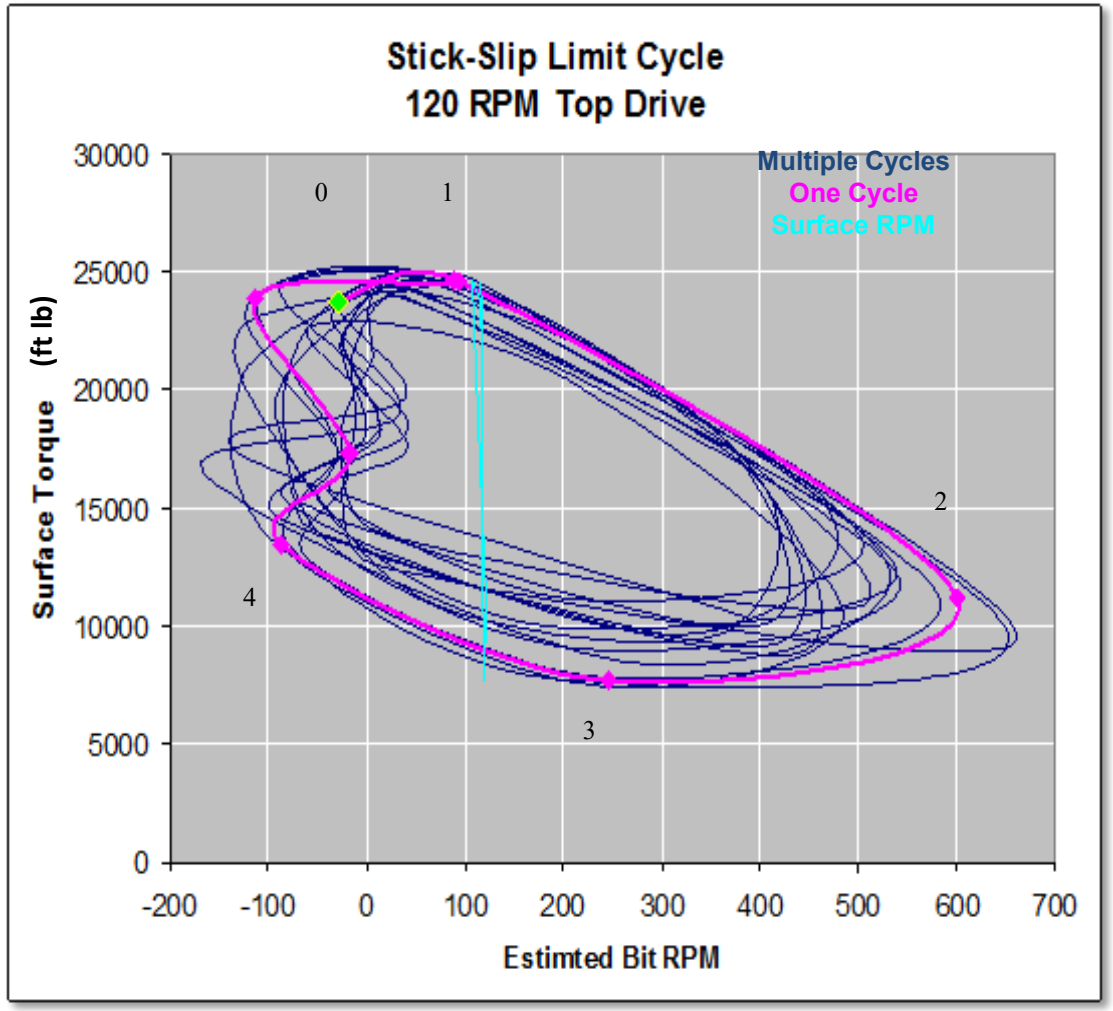
Torsional oscillation - winding and unwinding of the drill pipe

Stick slip - downhole RPM goes to zero

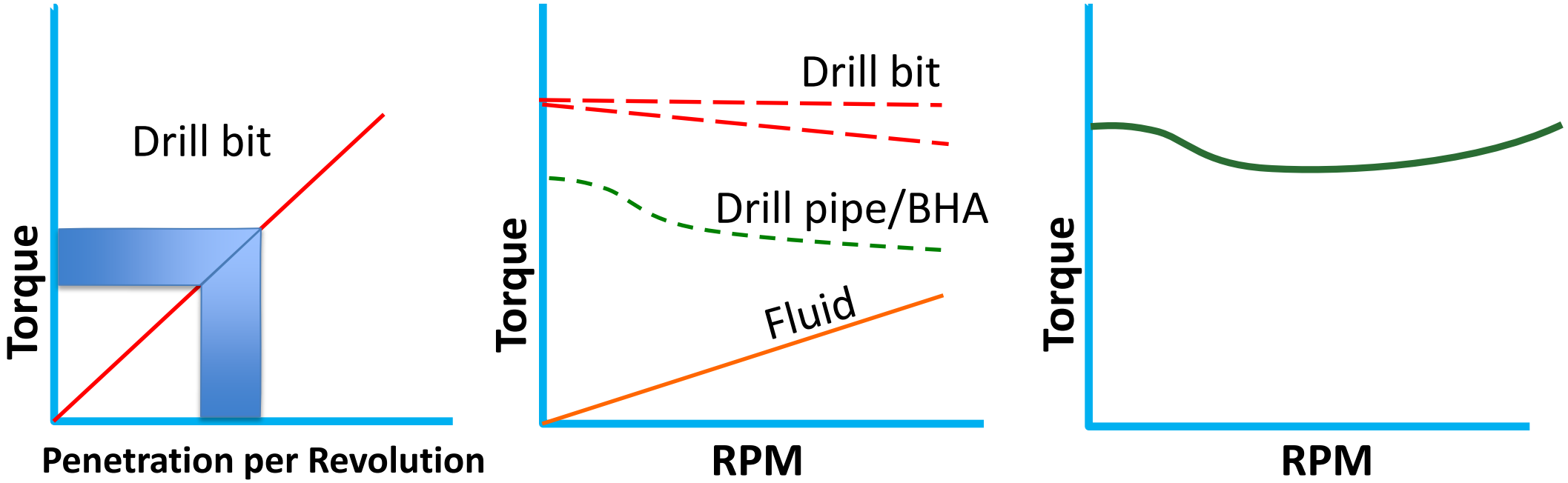
Often described as a self-excited limit cycle







Physics of Stick Slip – A More Complete Explanation



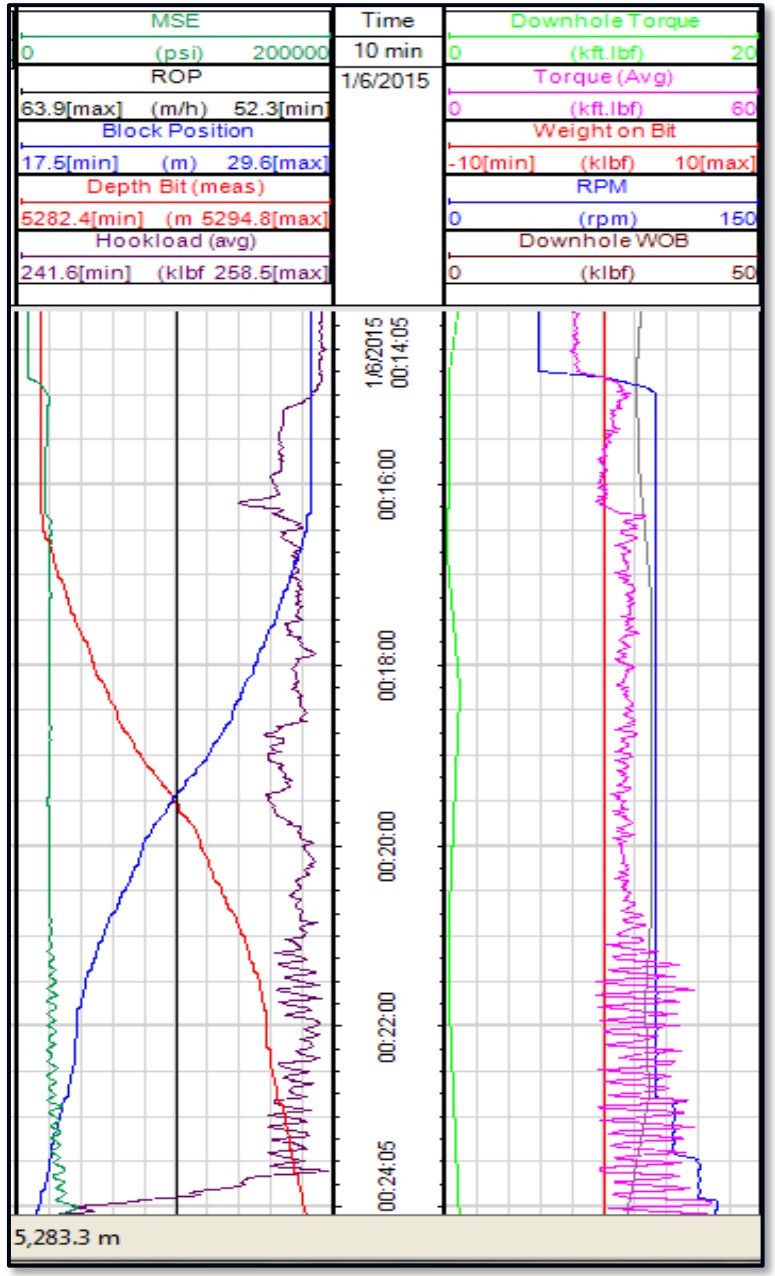
Details

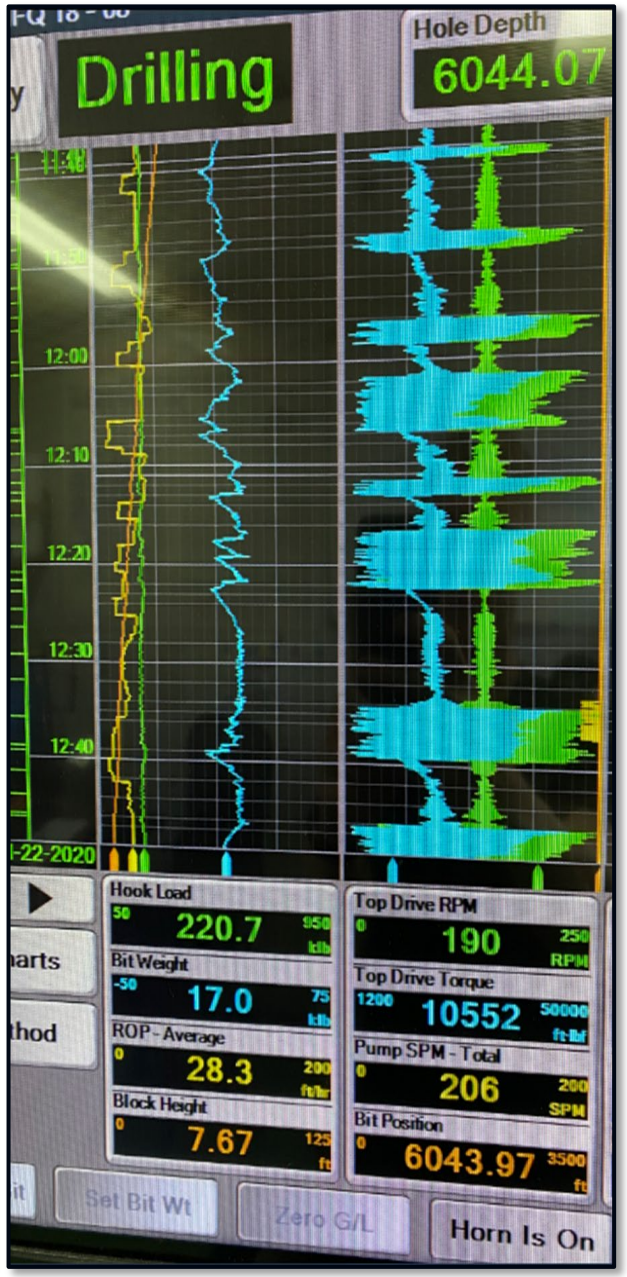
- Shear of the fluid between the pipe and hole wall
- Stribeck friction of the pipe and BHA against the hole wall and cuttings bed
- Torque of the bit due to penetration per revolution (which is a function of WOB)

Stick slip can be a limit cycle - self excited by friction

Can be driven by WOB, ROP, RPM

Why should we care about drill rig control systems?





Rig control systems affect stick slip

- Auto drillers
- Top Drive Controllers
- Heave Compensation Systems
- Pumps, Flow, and Downlinking
- Power Systems
- Automation Systems

Variation

- Weight on Bit (WOB) → ROP → Torque → Stick slip
  - Bit stalls
  - Motor stalls
  - Top drive stalls
  - Lateral vibration

Recent Examples

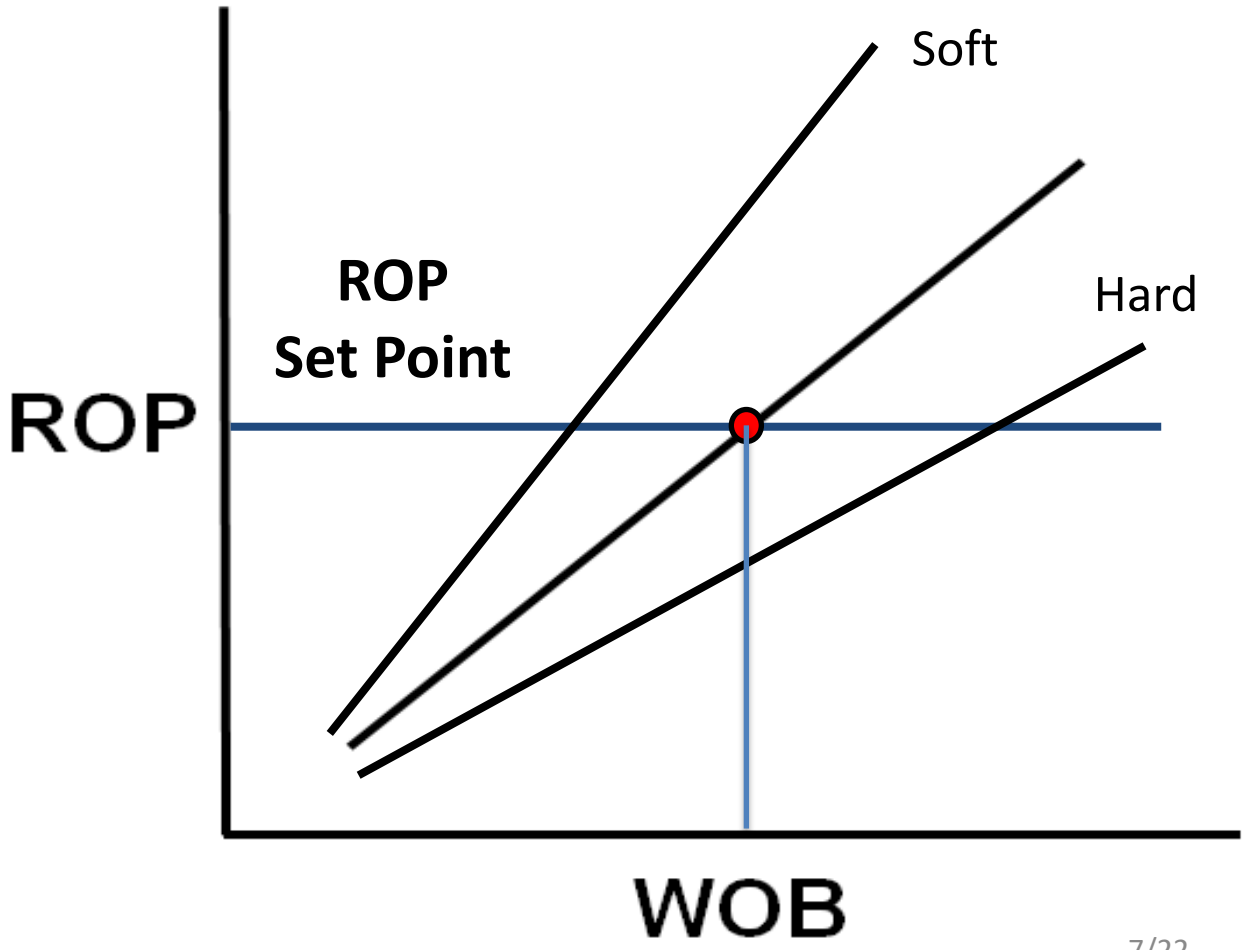
Auto Driller Theory

Auto drillers control the drum rotation rate

In Rate of Penetration (ROP) mode:

- It directly controls drum speed
- WOB will vary as rock strength changes
- ROP will be smooth
- ROP control is not adding noise

The slope of the WOB/ROP line is determined by the formation and drilling process.



Auto Driller Theory

Auto drillers control the drum rotation rate

In ROP mode:

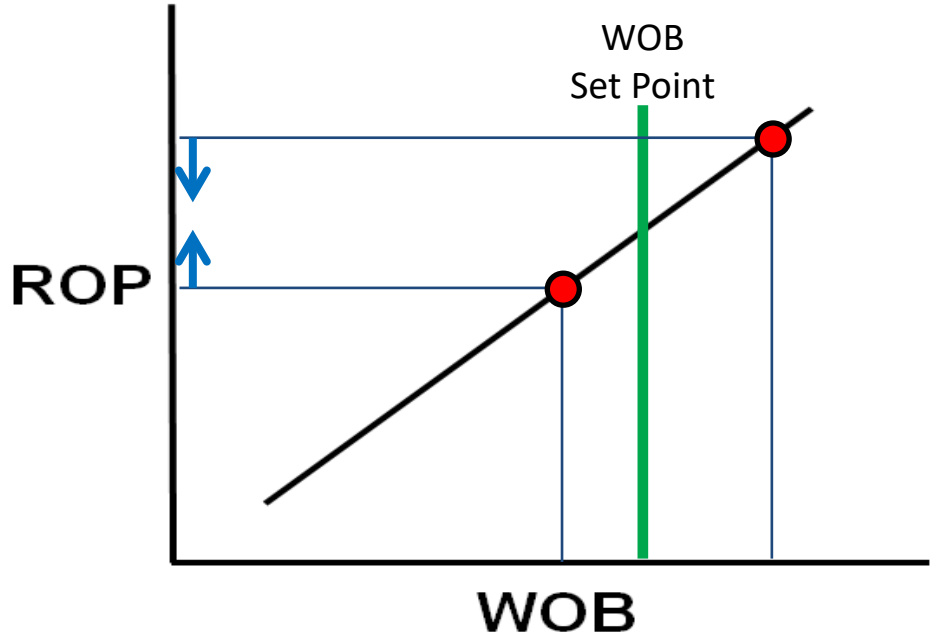
- it directly controls drum speed
- ROP will be smooth
- WOB will vary as rock strength changes

In WOB mode:

- If WOB is low → increase drum rotation rate
- If WOB is high →decrease drum rotation rate

The step size is determined by the controller

- Bang-bang or On-off Controller
- Proportional-Integral-Derivative (PID) Controller
  - Actually PI only is used due to noise in the derivative
- Model Predictive Controller (MPC)
- Multiple variations used on drill rigs



Auto Driller Practice: PI Controller

The step size for ROP is determined by the PI controller

P – Proportional to error, I – adjust for the integral error with time

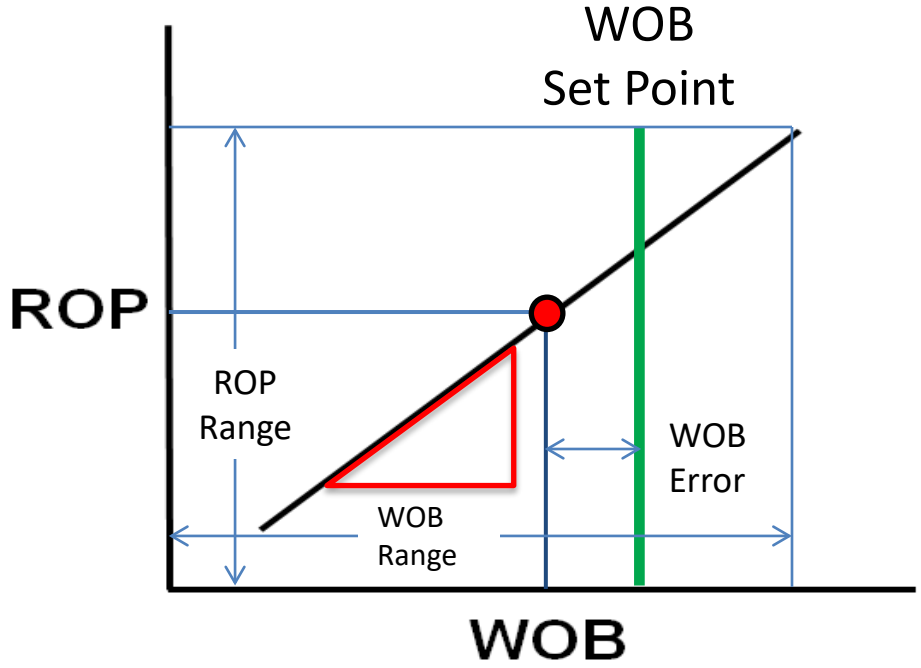
$$\Delta ROP = \frac{WOB_{error}}{WOB_{range}} * P_{gain} * ROP_{range} + \text{Integral term}$$

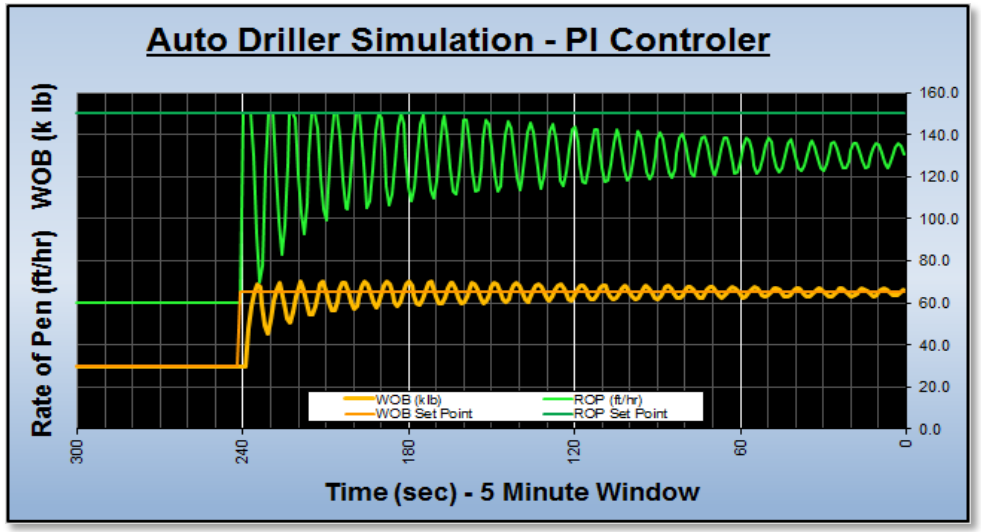
Stability depends on the P and I values

When gain is too high it behaves as if it is a bang-bang controller

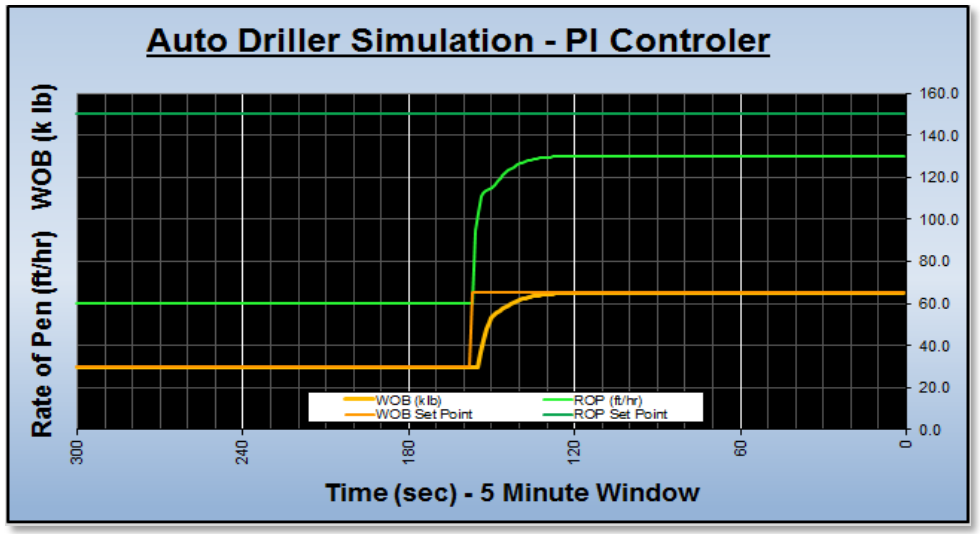
The controller must also use the correct ranges

i.e. $\frac{ROP_{range}}{WOB_{range}}$ equals the slope of the ROP/WOB line





Gain Too High

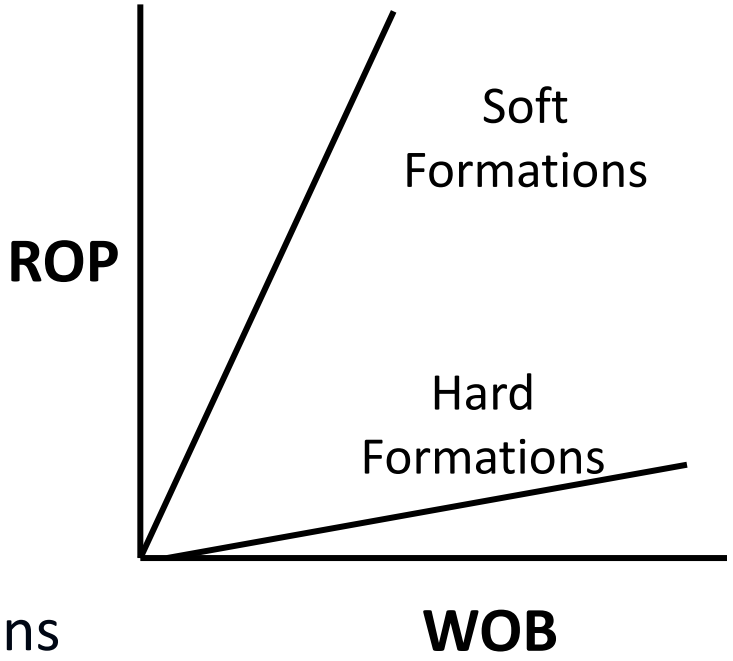


Gain Just Right

Drilling System Response - Tuning & Re-tuning the System

What affects the WOB/ROP relationship?

Hole Size - 24 inch to 6 inch	4:1
Formation Hardness - 45 ksi to 3 ksi	15:1
Rotary Speed - 240 RPM to 60 RPM	4:1
Bit Design – PDC to Roller Cone	5:1



This relationship can change by a factor of 200+ in one well

Since the relationship between WOB and ROP is not fixed

The gain needs to be adjusted for different drilling conditions

It cannot be set at the factory and left alone

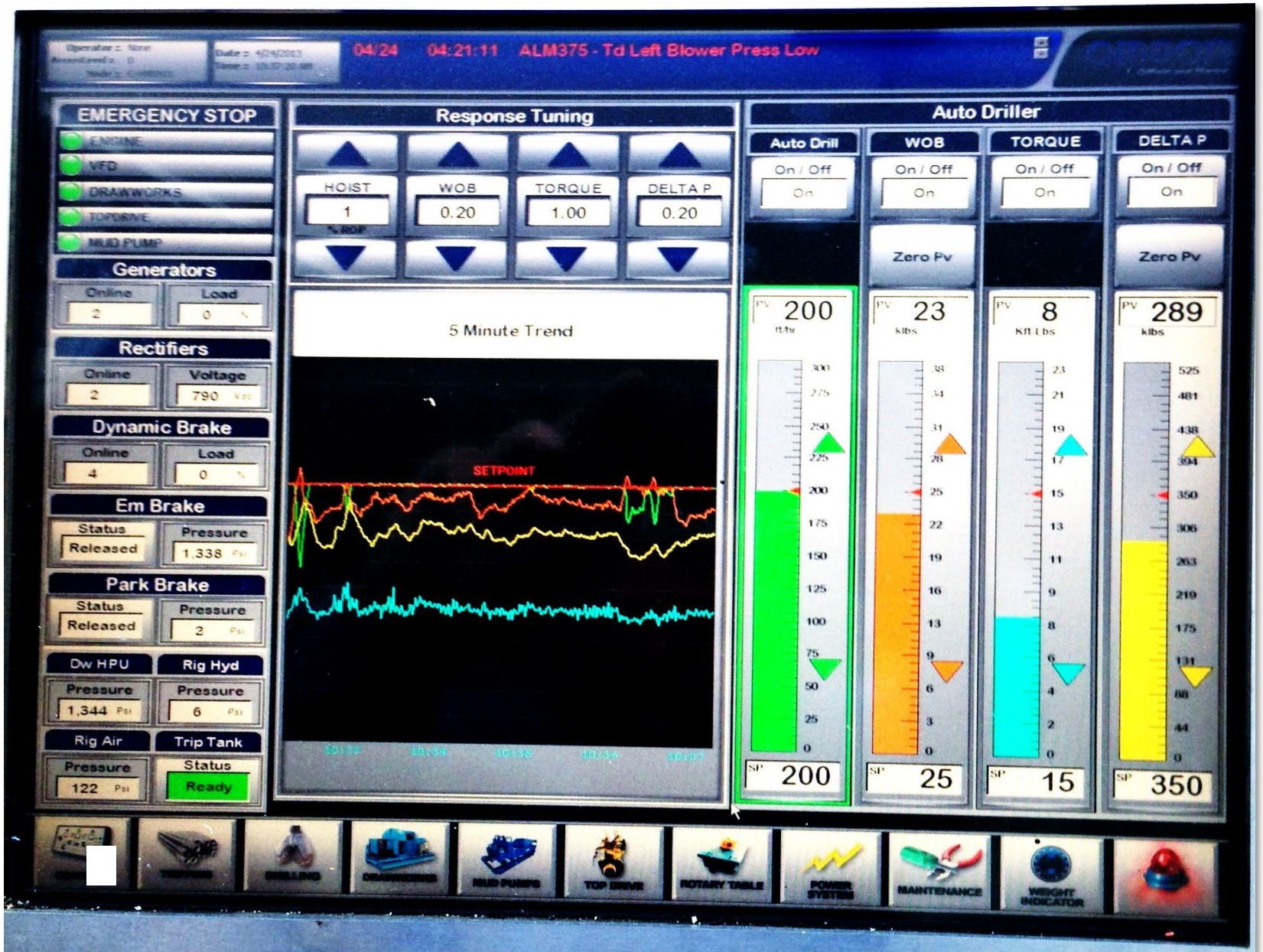
Rig documentation often does not cover how to diagnose and adjust the gain

Some auto drillers do not have rig site adjustment available (need upgrade)

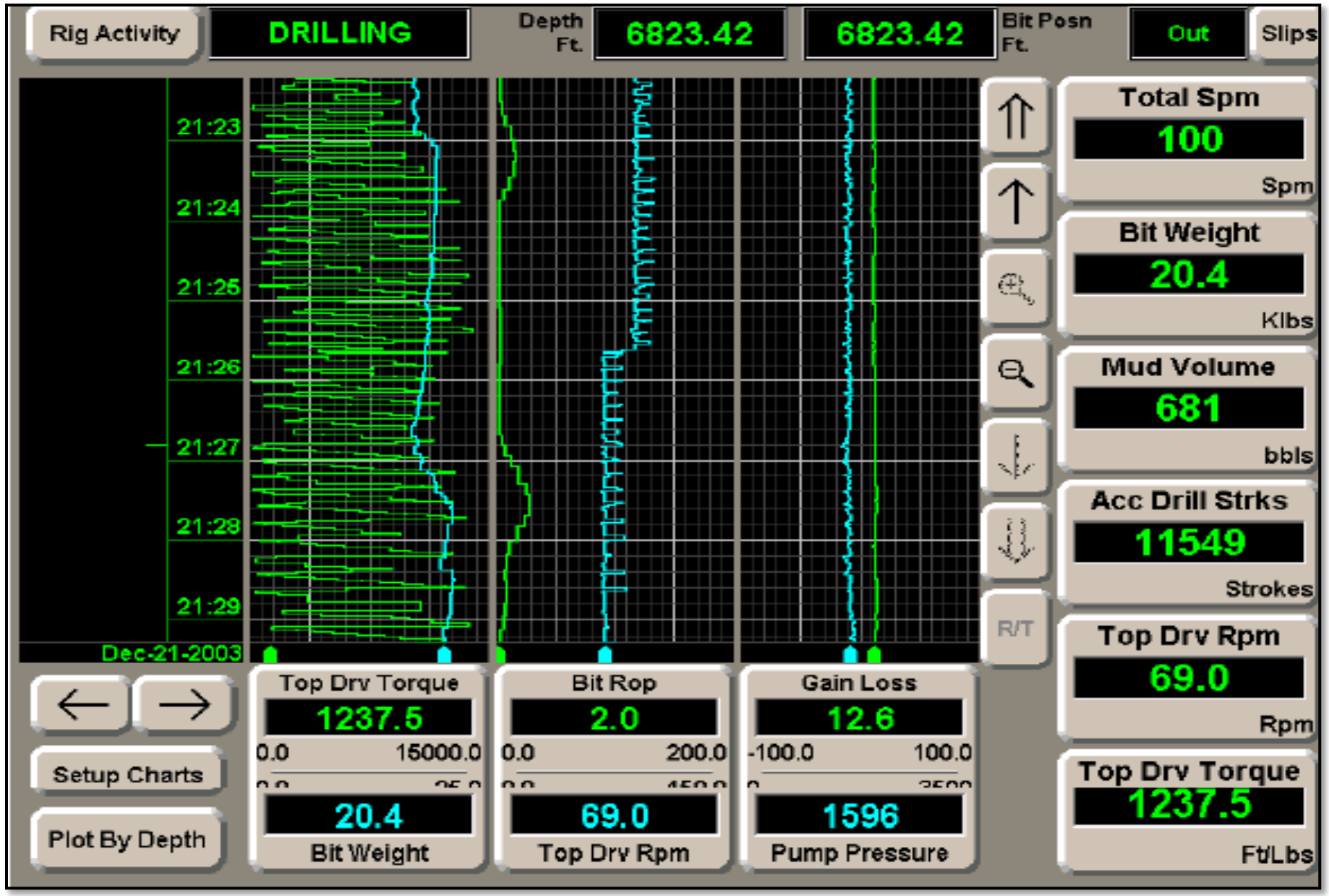
Work with contractors and OEM vendors on:

1) Training and documentation
2) System modeling to find robust control solutions offline

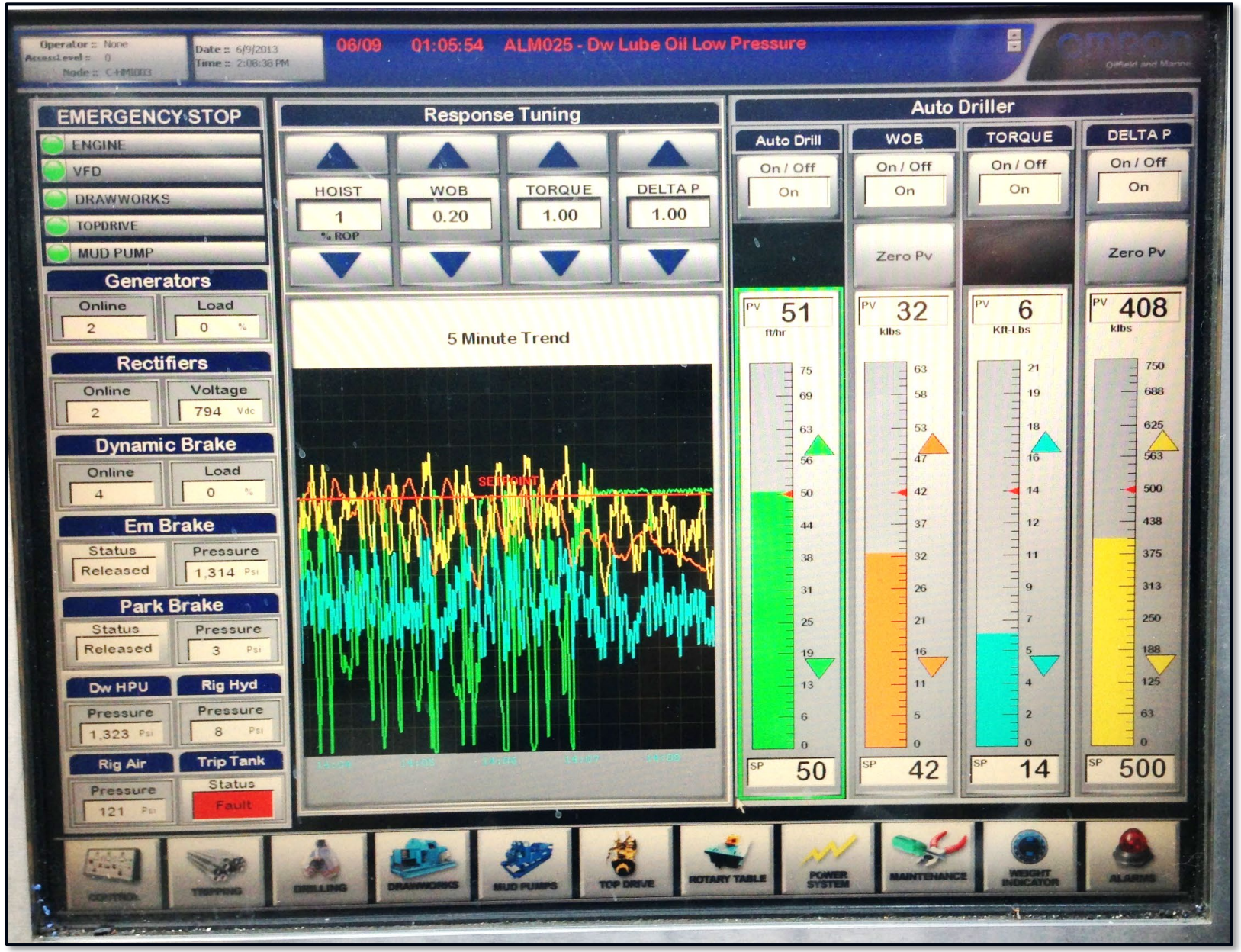
Detecting Dysfunction - Good ROP Control no Dysfunction



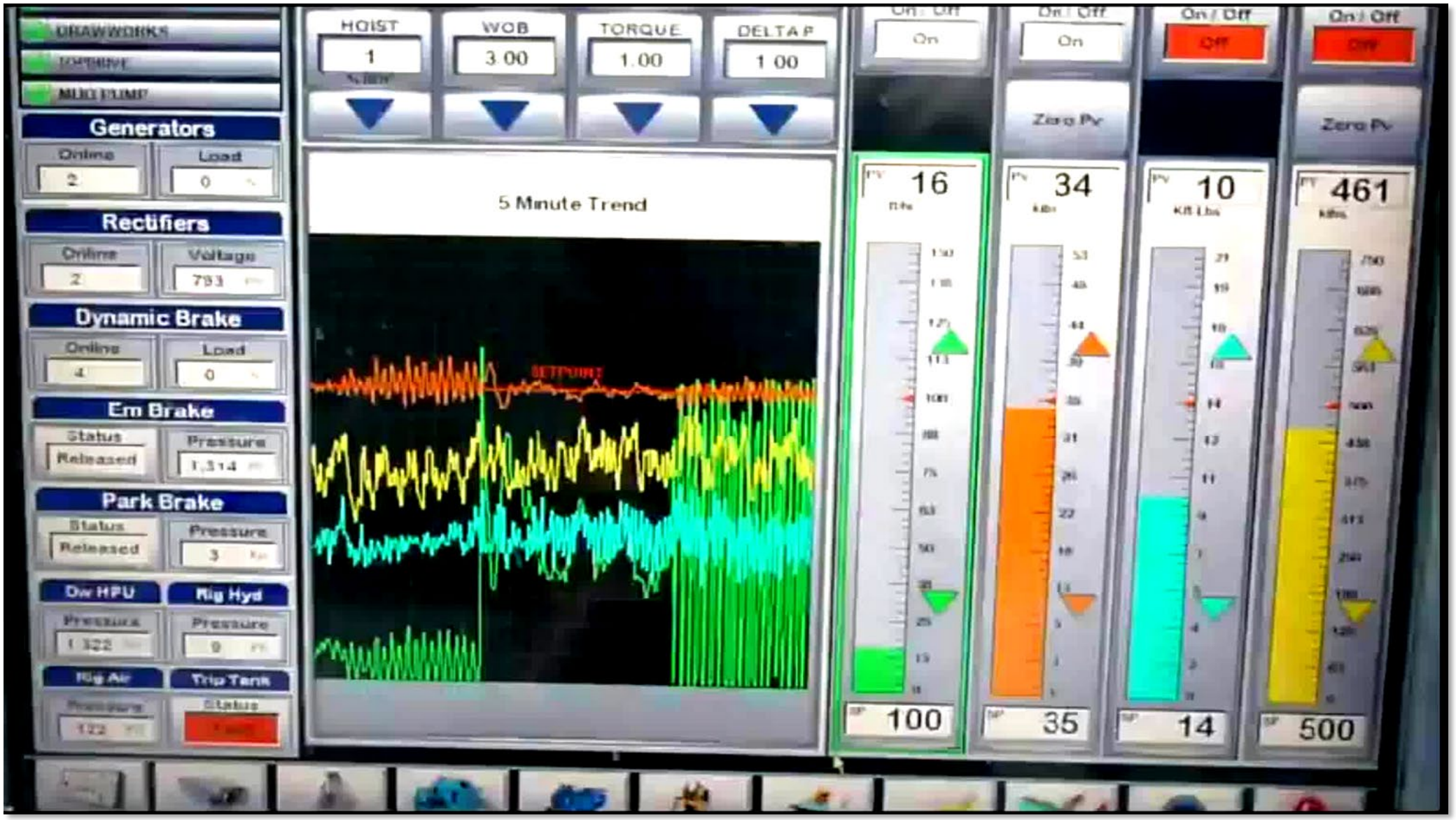
Detecting Dysfunction – Stick Slip w Good WOB Control



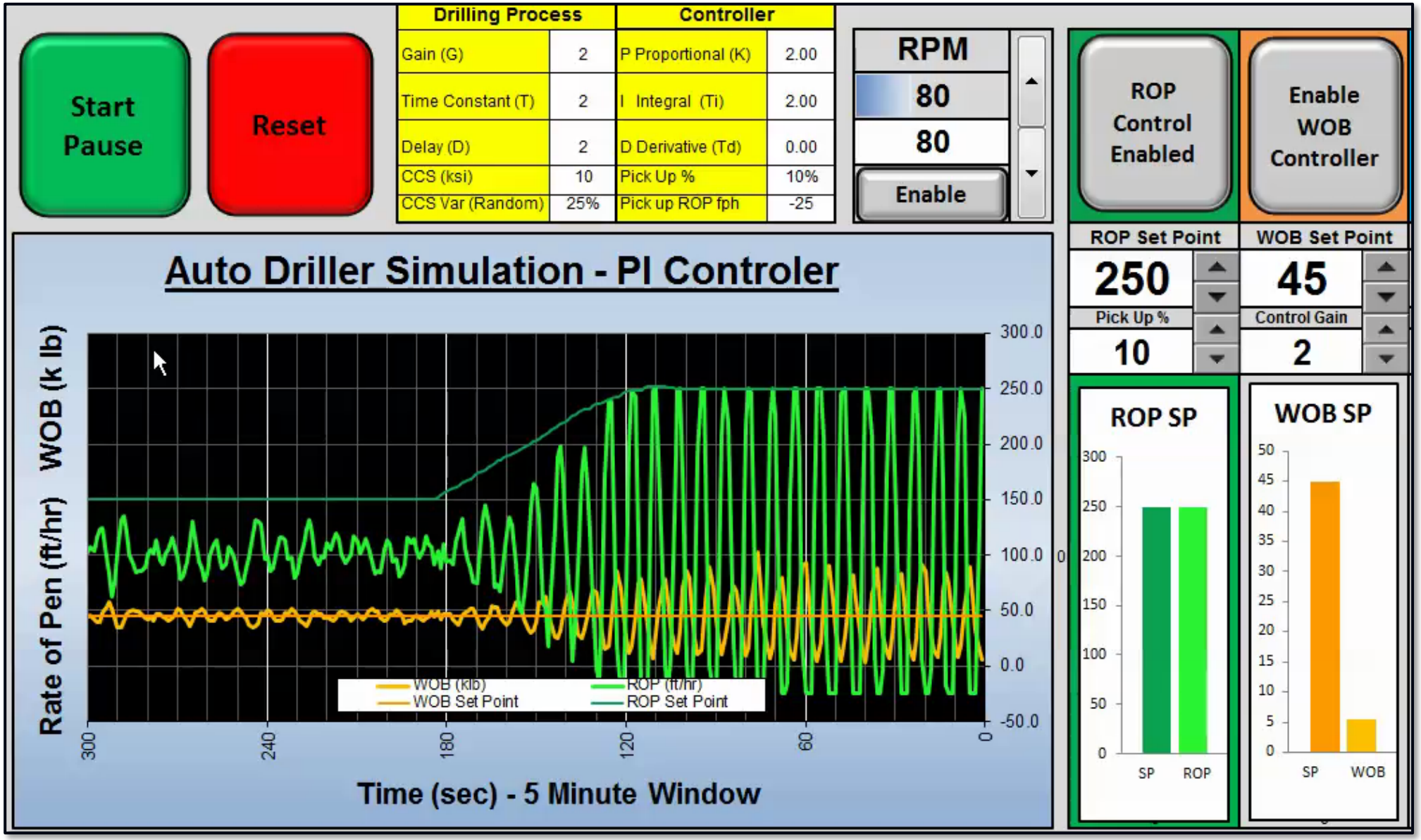
Detecting Dysfunction – Stick Slip Driven by WOB Controller



Improving Behavior - Tuning the Proportional Gain



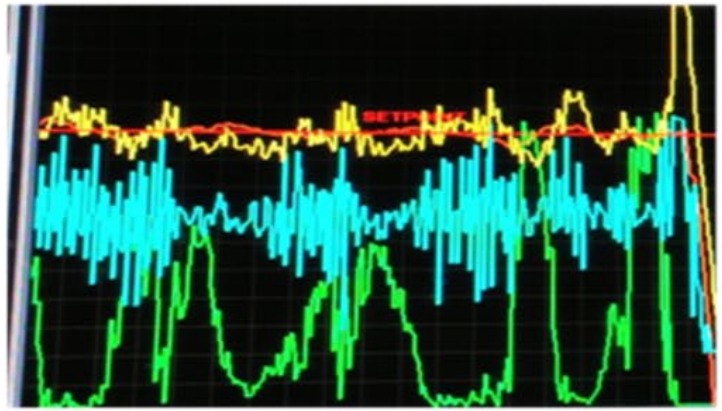
Improving Behavior – Modeling the Process and Controller

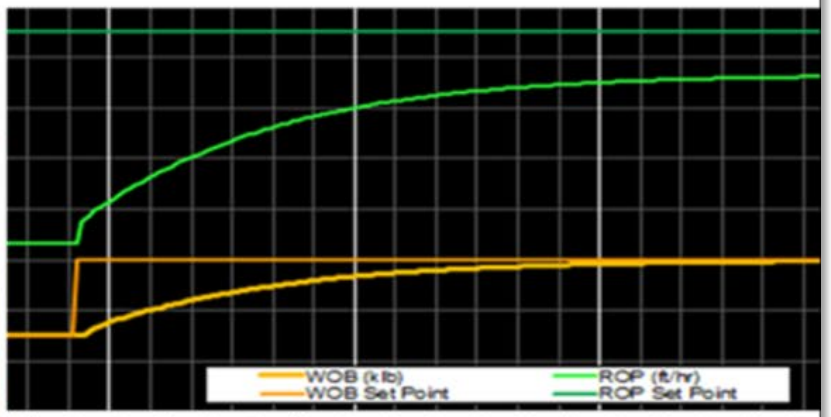


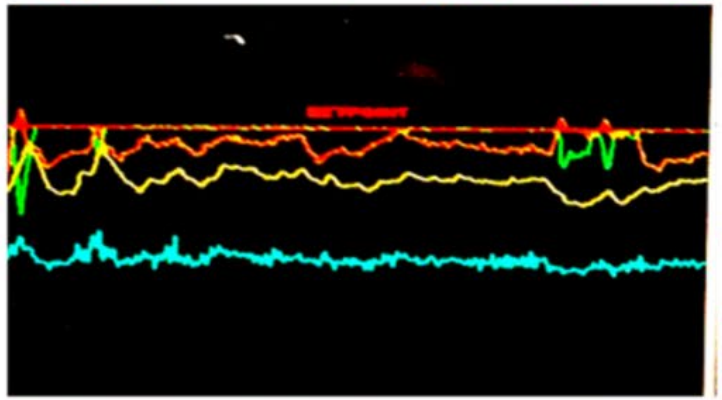
Improving Behavior – Training Drillers to Tune the Gain

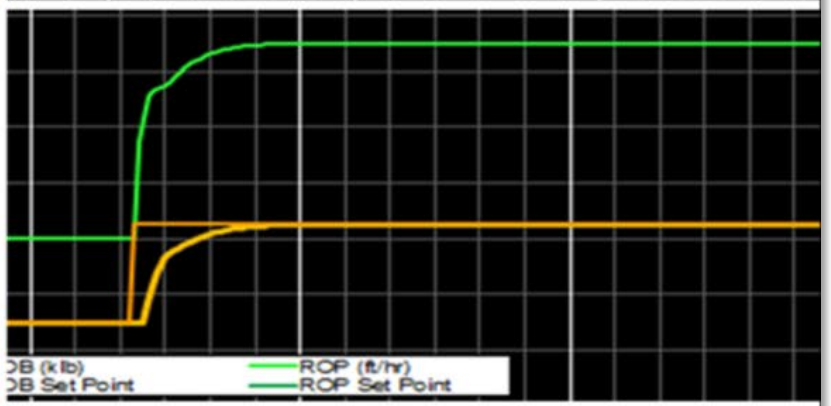
Rig Poster

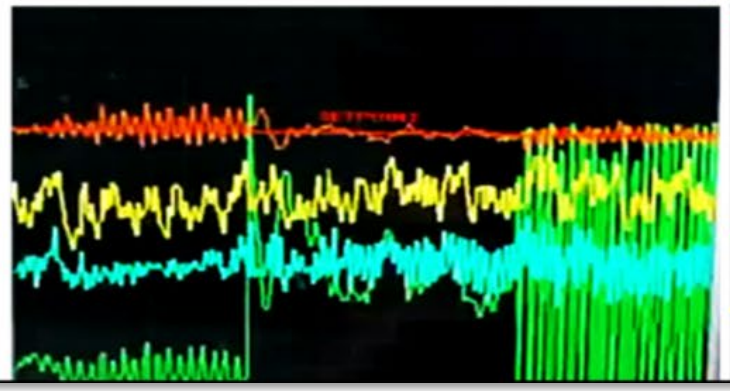
- Gain Too Low long response time
- Gain Just Right fast response, tracking well
- Gain Too High or ROP Setpoint Too High overshoot, "painting the screen"

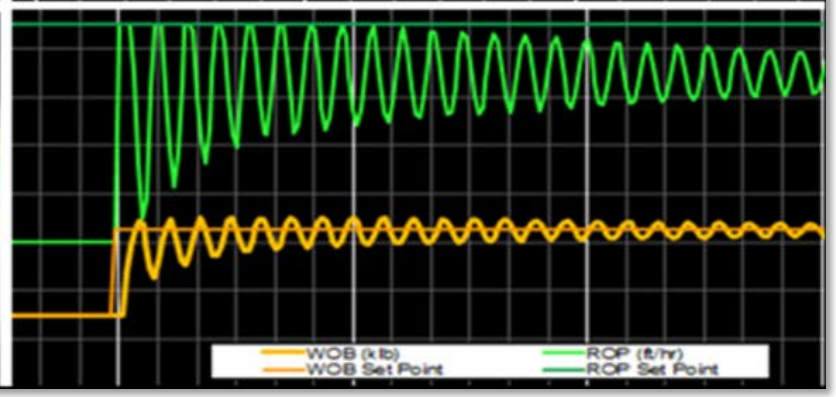












Conclusions

- Some dysfunctions are self imposed
- Multiple rig control systems can excite and/or drive stick slip
- The auto driller can have a major impact on system stability
- Crew training and tuning and can substantially improve performance
- Some auto driller systems must be upgraded to get access to tuning
- Managing torque limits is essential to improving system stability

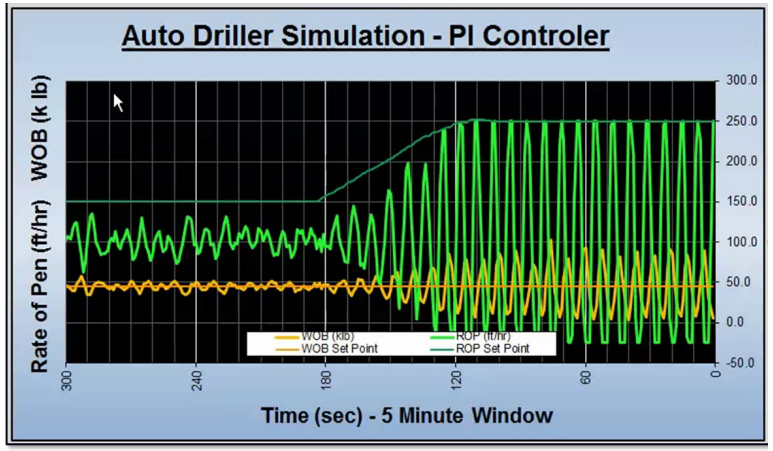
- Automation systems add another layer of complexity to the controllers
- The base system must be stable, with or without automation

Take Aways - Detection

If ROP is not smooth or torque has a large variation or multi second period we have an opportunity.

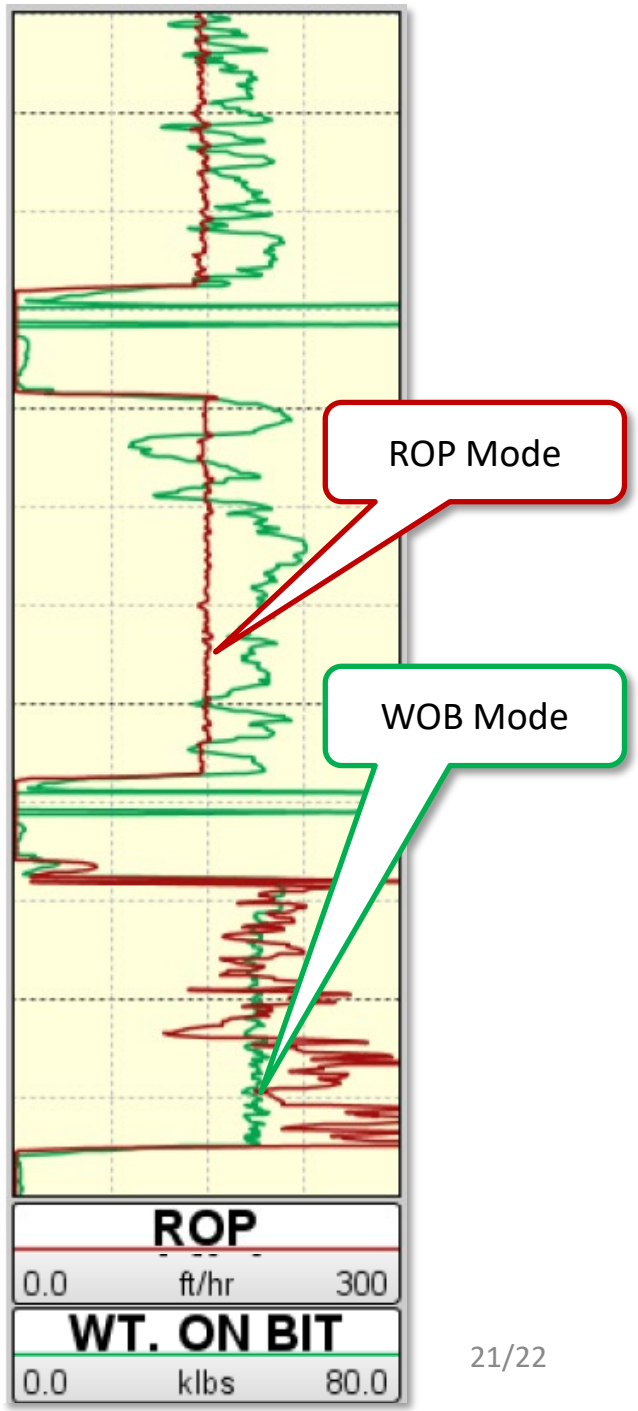
Determine the root cause of stick slip:

- Self Induced Stick Slip
- Auto Driller Driven
- Torque Limit Driven
- Heave, Downlinking, etc.



Stick slip is not Auto Driller Driven when:

- Off Bottom
- When in ROP mode
- Improves with clean up cycle



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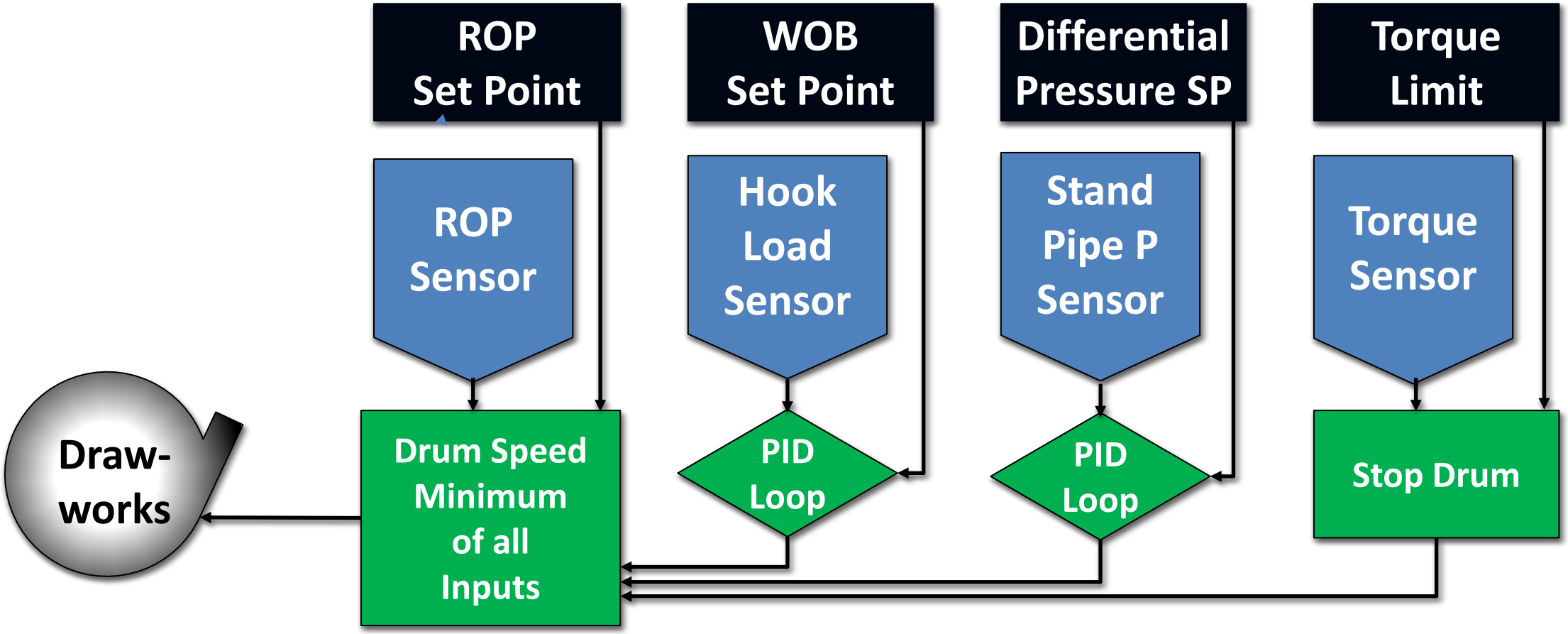
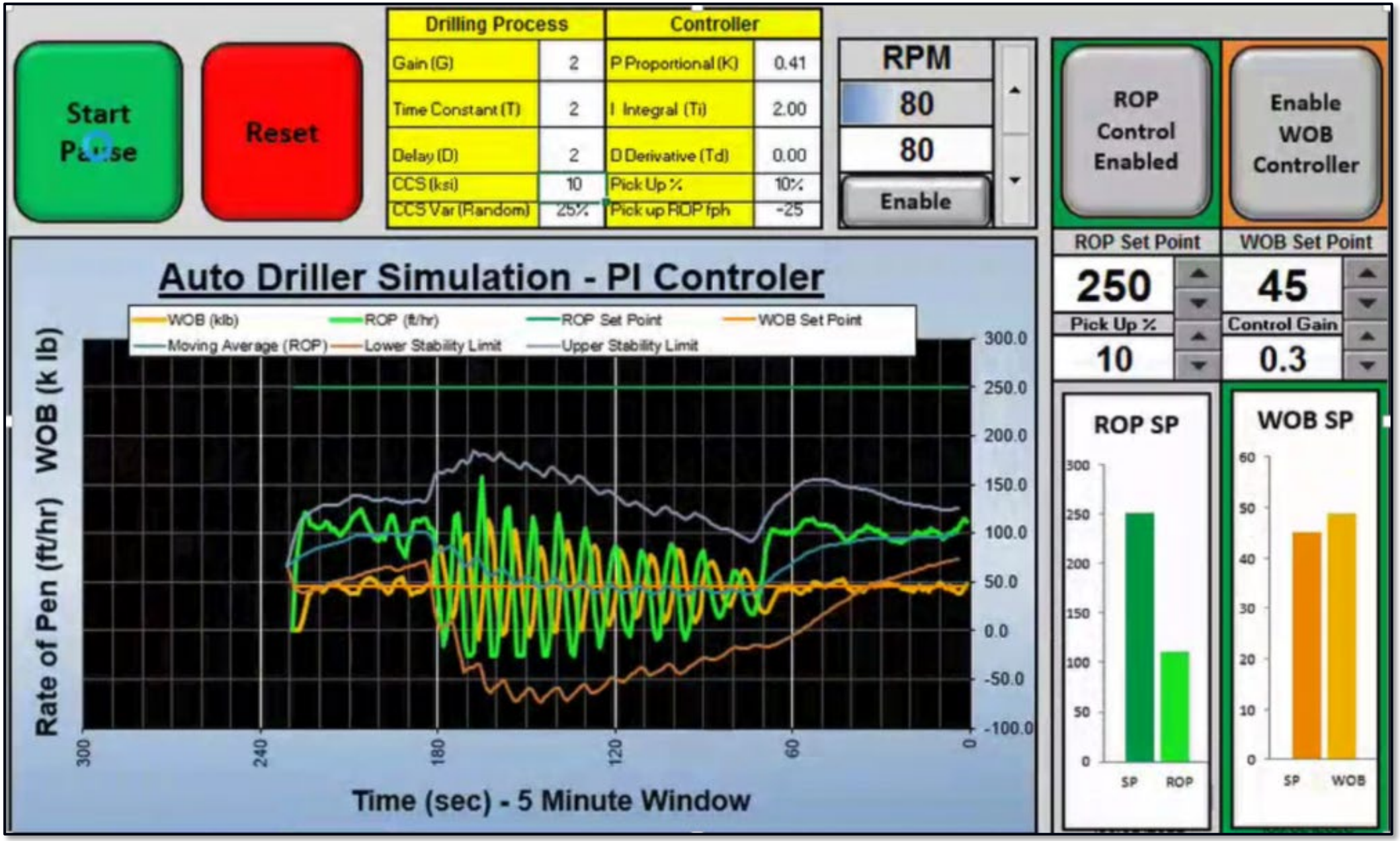
Back Up Slides

Auto Driller Theory - Multiple Loops In Control

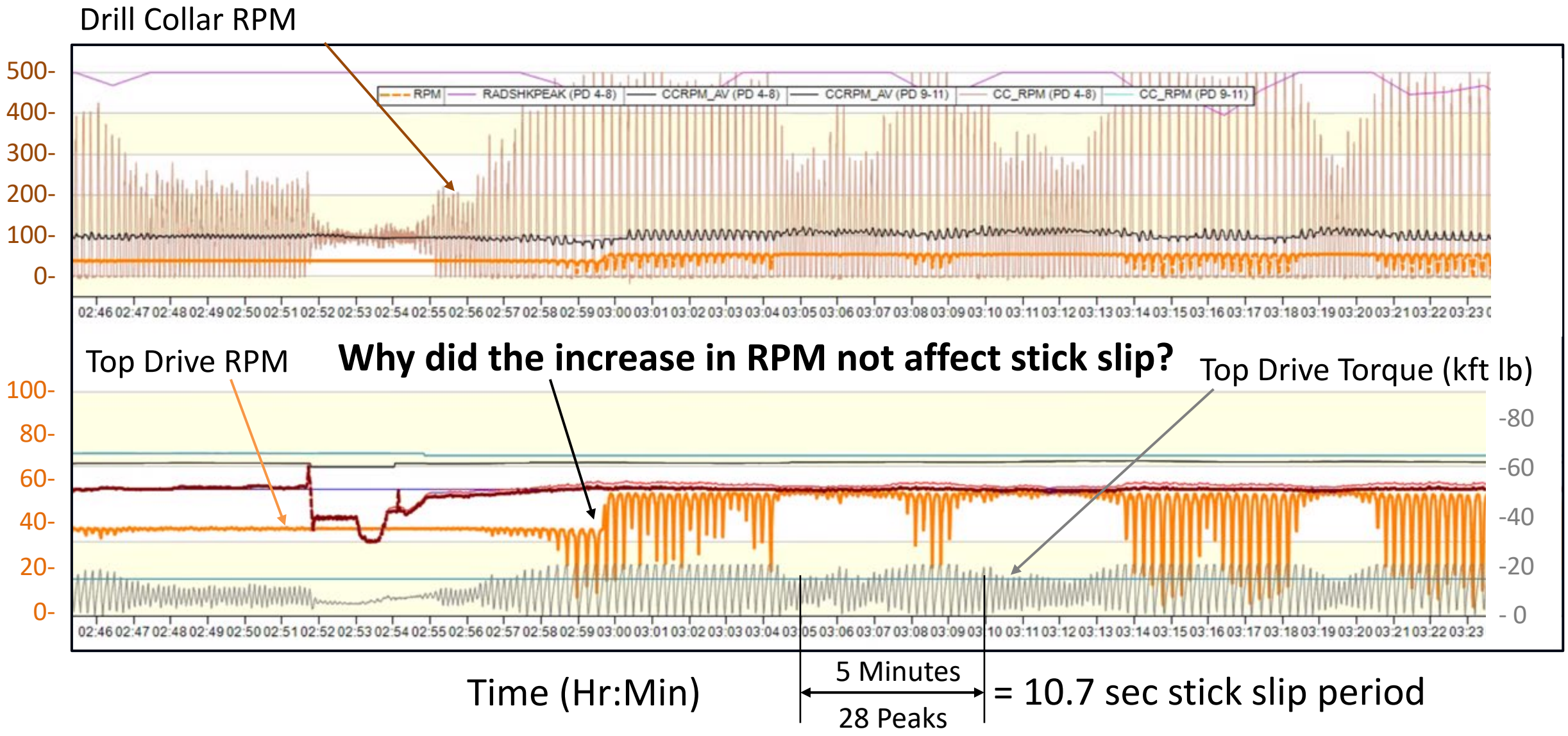


Notes: Auto drillers control the drum speed
Multi loop controllers control drum speed so no loop exceeds its set point or limit
PID - Proportional-Integral-Derivative controller adjusts input based on error

Improving Behavior - Automatic Tuning



Top Drive Stalling Reinforces Stick Slip

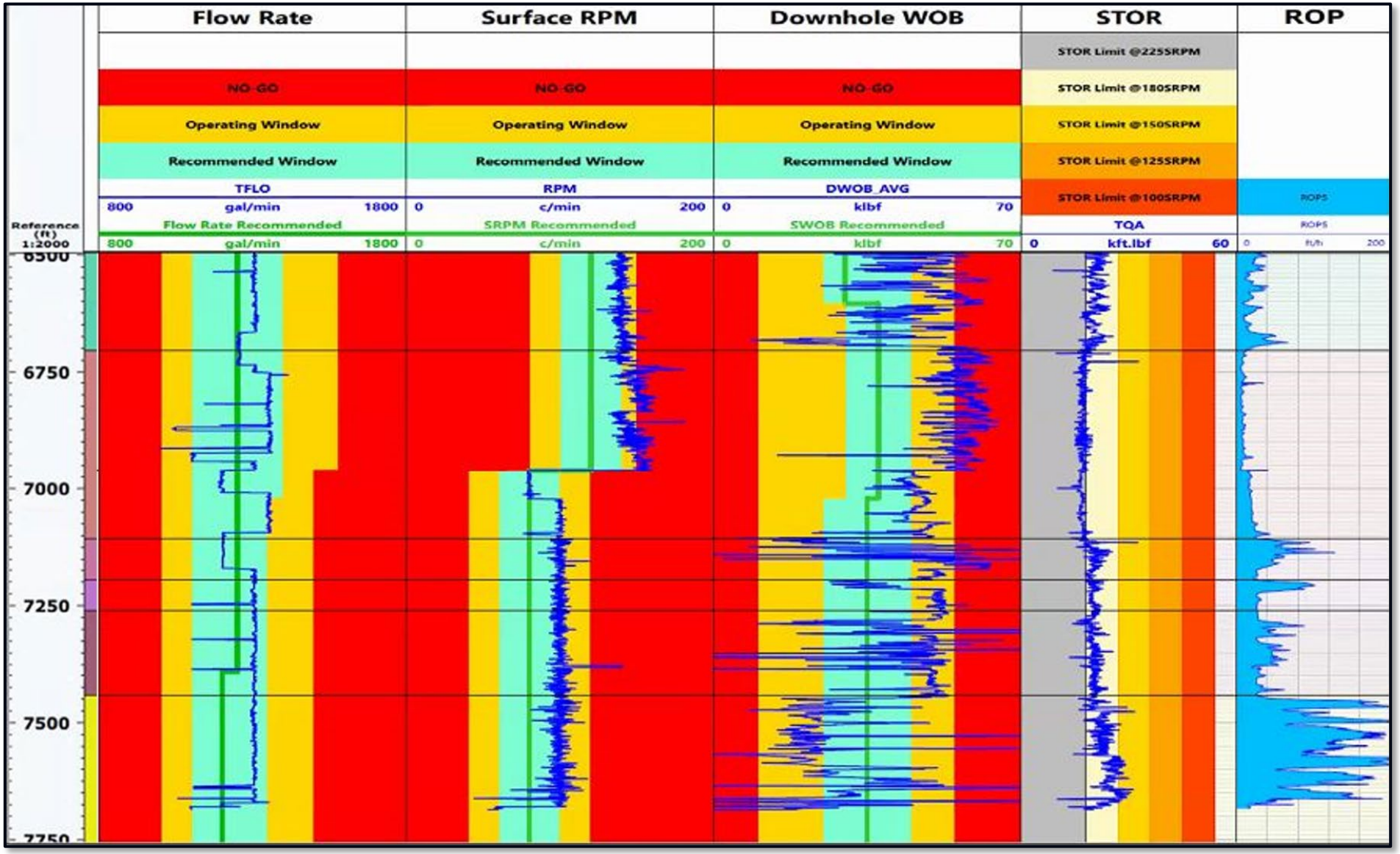


References

- SPE 173045 - Drilling Modeling and Simulation: Current State and Future Goals
- SPE 174874 - A Framework for Transparency in Drilling Mechanics and Dynamics Measurements
- SPE 181415 - Drill Rig Control Systems: Debugging, Tuning, and Long Term Needs
- SPE 191417 - Auto-Driller Automatic Tuning
- SPE 194082 - Creating Open Source Models, Test Cases, and Data for Oilfield Drilling Challenges

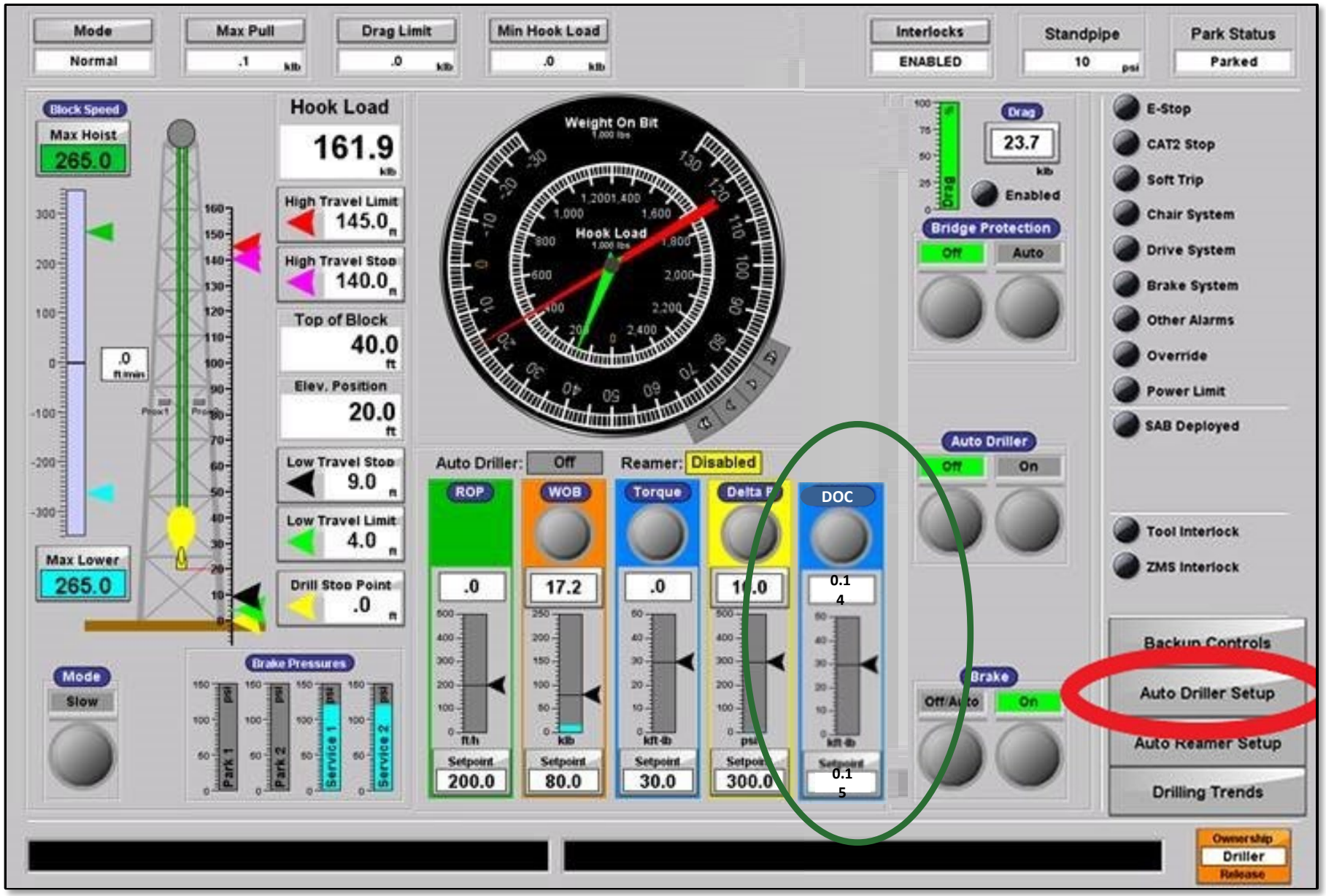
Take Aways - Proposed Controller Improvements

- Automatically detect and correct for stability
- Display Roadmap windows on the drillers screen
- Include system settings in the roadmap
- Automatically switch to next section based on measured depth
- Auto correlate with offsets and give drill team edit capabilities

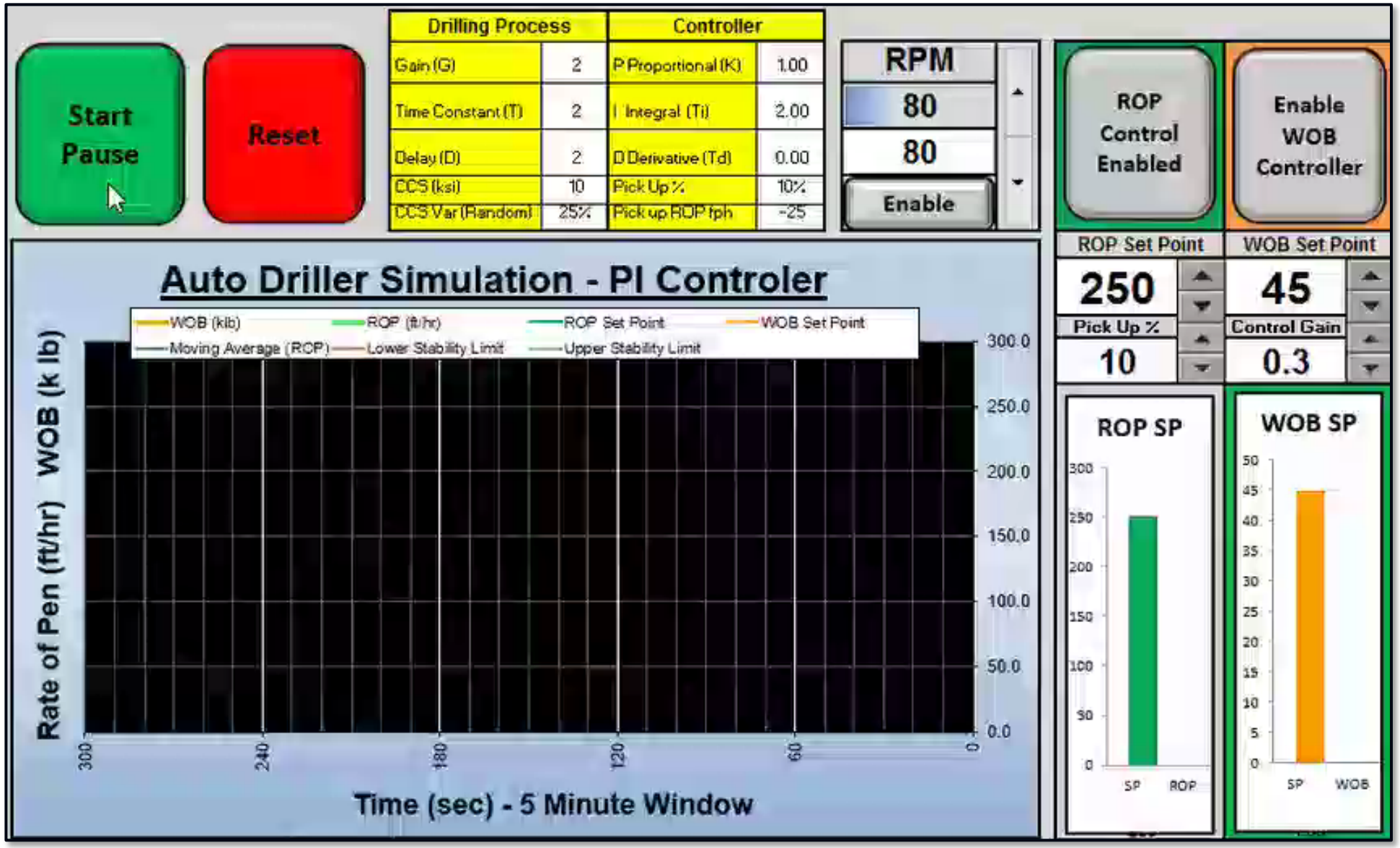


Proposed Improvements to Controllers

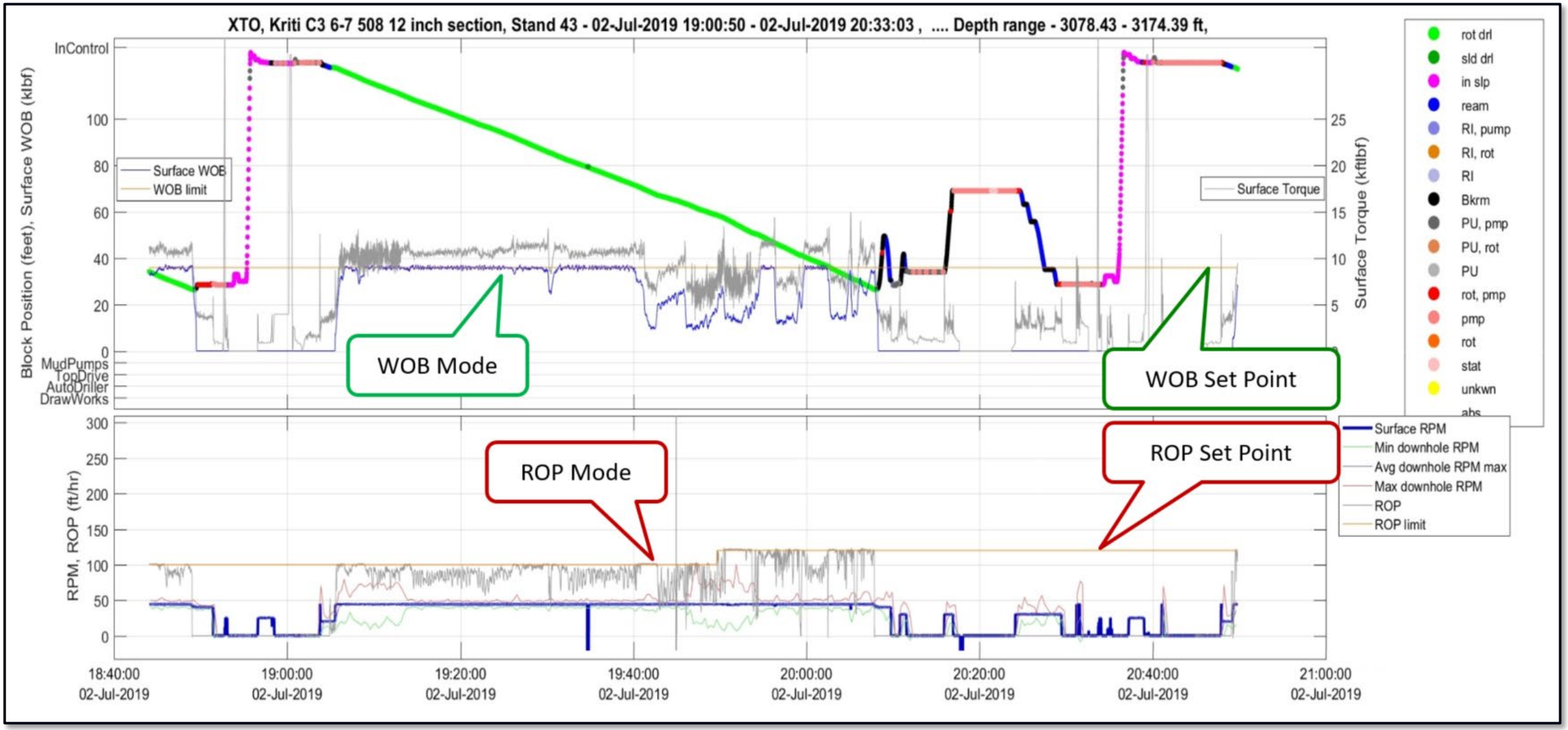
- Unconditional control system stability for all channels
- Add Depth of Cut Control (DOC)
- Give Clear Guidance on
  - Auto Driller
  - Top Drive and
  - Automation Torque Limits



Improving Behavior - Automatic Tuning



Improving Behavior – Example of Bumpless Transfer Between WOB and ROP Control



Why should we care about drill rig control systems?

Stick slip is bad…for bits, motors, BHAs, top drives, azimuthal tools

1. Weight on Bit (WOB) variation adds to ROP variation
2. ROP variation adds to torque variation
3. Torque (TQ) variation can stall motors and excite stick slip
4. Stick slip can excite lateral vibration

Lateral vibration is bad…

1. Destroys bits
2. Increases stress on electronics and pin connections
3. Leaves ledges in the hole
4. Leads to more bit stalling and motor stalling

Improving Behavior – Modeling the Controller